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Environmental Conditions Responsible for Solar Activity

Annual Technical Report

For the Period 01 Oct. 92 through 01 Oct. 93

Principal Investigator: Professor Peter A. Sturrock

Grant No.: F49620-92-J-0015

Program Manager: Dr. Henry R. Radoski

CENTER FOR SPACE SCIENCE AND ASTROPHYSICS

STANFORD UNIVERSITY

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During the past year, the Stanford group has continued its investigations into the origins of solar coronal activity. Solar activity occurs within a complex magnetic environment, which is determined by the entire history of magnetic flux emergence and surface flows at the underlying photosphere. One of our main achievements has been the development of a technique to reconstruct the coronal magnetic field above active regions from measurements of the magnetic field at the photosphere. To complement this empirical tool, we have continued our theoretical work on the influence of photospheric shearing motions on the configuration and energy content of coronal fields. This work is shedding light on the nature of eruptive phenomena such as coronal mass ejections. We have also intensively evaluated the role of magnetohydrodynamic waves and reconnection in heating the solar atmosphere, and identified a number of promising coronal heating scenarios that will require detailed numerical modeling.

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1. Introduction

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2. Studies of coronal magnetic fields

One of the main impediments to an improved theoretical understanding of solar flares and eruptive phenomena is that the coronal magnetic field cannot be directly observed. The spectroscopic phenomena that permit the deduction of the vector magnetic field at the level of the photosphere cannot be used to determine the field at higher levels.

Roumeliotis (1993) has devised a method for reconstructing the coronal magnetic field above an active region using vector magnetic field measured at the photosphere, together with the assumption that the coronal field is essentially force-free. The computation begins with the potential field that matches the vertical component of the field at the photosphere, and then proceeds to systematically adjust the coronal configuration until the computed field is force-free and matches the observed vertical and transverse components of the field at the photosphere. An example of how this method works on real data is shown in the following diagrams, which present the view from directly above the active region. Figure 1 shows the potential field lines in the vicinity of the magnetic neutral line, while Figure 2 shows the corresponding field lines of the reconstructed force-free field. A striking feature of the reconstructed coronal field is the dramatically different connectivity of the field lines. Also, the force-free field is strongly sheared near the neutral line - a feature commonly associated with pre-flare active regions observed in Hα.

Klimchuk and Canfield (1993) studied the influence of vector magnetograph measurement errors on the inferred properties of coronal magnetic fields. They set limits on the accuracy with which the coronal field can be known, given the uncertainties of the vector magnetograph data.

Our semi-empirical studies of coronal force-free fields will be refined and extended during the next year. In collaboration with our observer colleagues at the National Solar Observatory at Sacramento Peak, we plan to investigate such basic issues as the coronal structure of active region magnetic fields associated with solar flares.

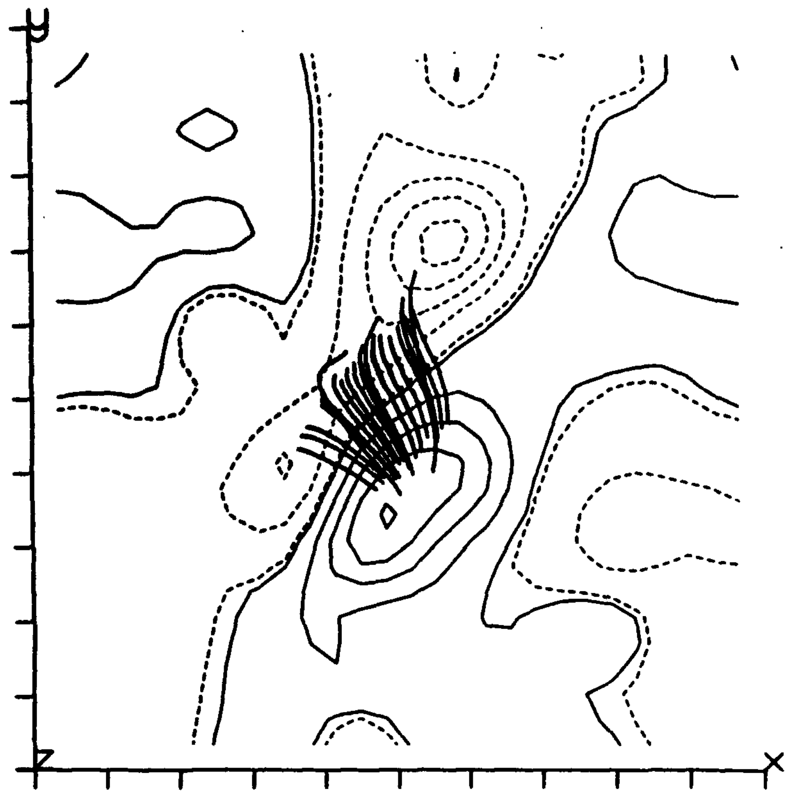

Figure 1.

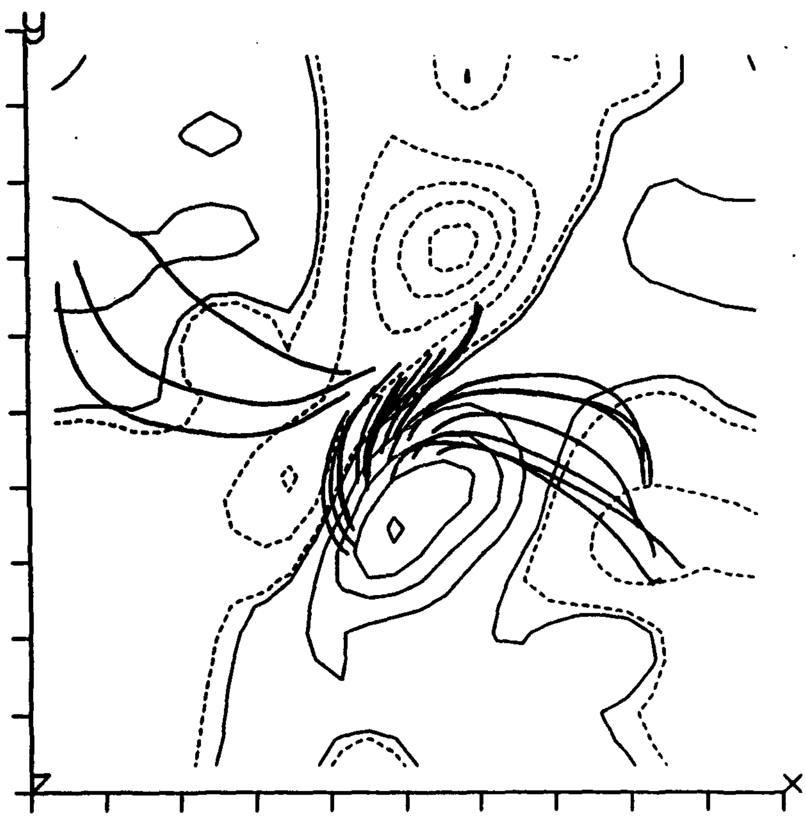

Figure 2.

Roumeliotis, Sturrock and Antiochos (1994) concluded a computational study (using the Cray X-MP at NRL) on the effects of shearing flows on coronal magnetic fields. The idealized physical model is illustrated in Figure 3. The initial magnetic field is simply that from an isolated dipole embedded in the center of the Sun. Steady surface flows are imposed that have only a latitude-dependence and are anti-symmetric about the equatorial plane. The results of the computations show that when the surface flows are initially applied, the coronal field expands steadily outwards, until the footpoints of the magnetic field are separated by a certain critical amount. Beyond this point, the coronal field expands dramatically for small additional increases in the footpoint separation. This phase of rapid expansion is suggestive of the lift-off phase of coronal mass ejections.

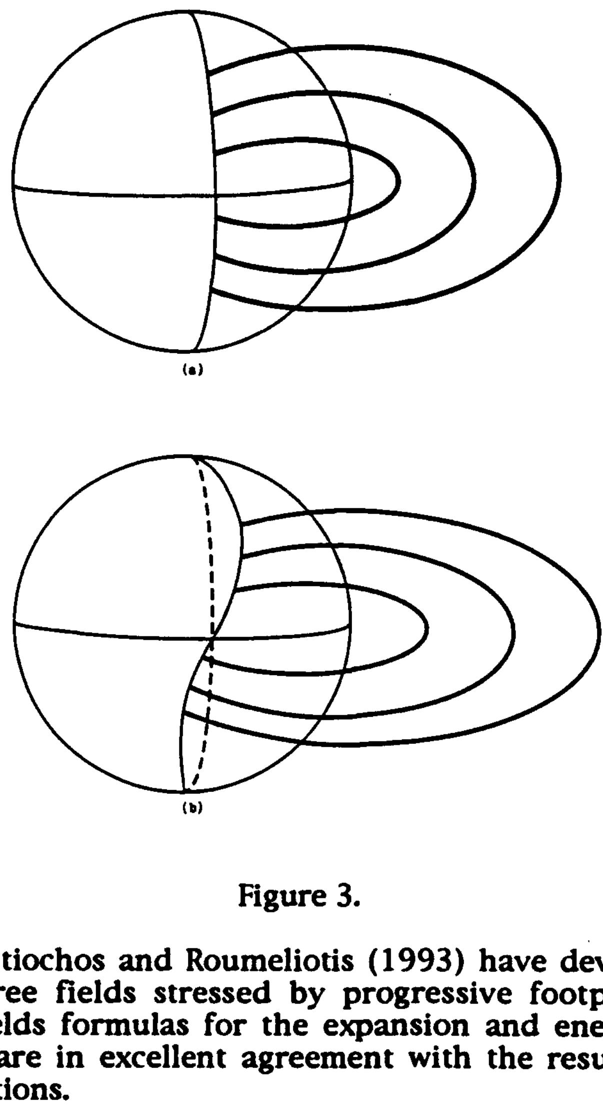

Figure 3.

Sturrock, Antiochos and Roumeliotis (1993) have developed an analytic theory for force-free fields stressed by progressive footpoint motions. The analytic theory yields formulas for the expansion and energy content of the coronal field that are in excellent agreement with the results of our detailed numerical computations.

During the next year, we plan to make our computational model more realistic by incorporating the effects of finite gas pressure and gravity. These modifications will allow us to simulate the eruption of coronal mass ejections beyond the lift-off stage.

3. Studies of coronal heating

Klimchuk (1992) reviewed the properties of one-dimensional hydrodynamic loop models for magnetically-closed regions of the solar atmosphere. Such loop models are invaluable for predicting the observational consequences of proposed coronal heating mechanisms .

Klimchuk and Porter continued their analysis of soft X-ray images from Yohkoh to provide an extensive data base of properties of coronal loops, including pressures, temperatures, lengths, and widths.

Porter, Sturrock and Klimchuk (1993) studied the collisional damping of fast-mode and slow-mode magnetoacoustic waves in uniform media and media with non-uniform "slab" geometries. They concluded that slow mode waves can contribute to heating the corona if an efficient source for their production can be identified.

Roumeliotis and Moore (1993) developed the first self-consistent analytic model of neutral point reconnection driven by converging footpoint motions. On the basis of this model, they concluded that it is unlikely that an extended current sheet can be formed by bringing together the footpoints of a quadrupolar magnetic configuration, as illustrated in Figure 4. Instead, electric current sheets must be transient structures that are created during the eruption or sudden internal readjustment of large-scale magnetic field configurations.

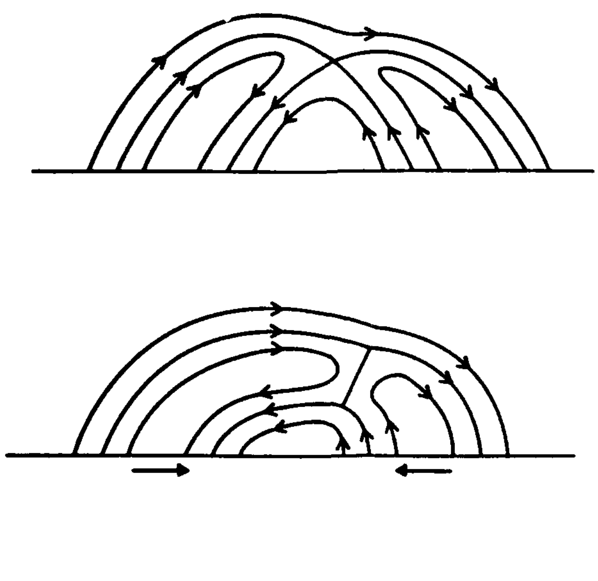

Figure 4.

Our analysis of the observational facts and existing coronal heating scenarios has focused our attention on two particularly attractive models for coronal heating that we plan to model through detailed numerical simulation.

First, we will study the própagation of magnetohydrodynamic waves through a magnetic field whose field lines are stochastically wound around each other. This is likely to be the case for the magnetic field lines above a solar active region, and our estimates indicate that mode coupling in such a magnetic environment will lead to the rapid production of slow mode waves which are efficiently dissipated.

Second, we will study a model for magnetic energy release by the formation and propagation of a front of intense electric current density and anomalously large electrical conductivity through the active region plasma.

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